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Effects of Broiler Litter and Nitrogen Fertilization on Uptake of Major Nutrients by Coastal Bermudagrass

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ABSTRACT

Land application of poultry litter provides essential nutrients for hybrid bermudagrass [*Cynodon dactylon* (L.) Pers.] production, but ammonia (NH_3) volatilization and N mineralization influence the amount of litter N available for plant uptake. Our objective was to determine the combination of broiler litter and fertilizer N, which maximizes the yields of forage and N, P, and K by 'Coastal' bermudagrass. Studies were conducted for 3 yr (1999–2001) in pastures at Newton and Mize, MS that differed widely in soil test P (STP) due to history of litter application (0 vs. 30+ yr, respectively.). Litter rates of 0, 4.5, 8.9, 13.4, and 17.9 Mg ha^{-1} were obtained by up to four monthly (April–July) applications of 4.5 Mg ha^{-1} and were supplemented with ammonium nitrate (NH_4–NO_3) to provide the same total N in each treatment. At Newton, combining litter with fertilizer N increased forage yield by 10% in 1999, 25% in 2000, and 34% in 2001, as compared to fertilizer N. At Mize, K uptake increased as litter rate increased in 2001 only. These responses to litter were related to increased soil P and K at Newton, and increased soil N, P, and Ca at Mize. Averaged across years, maximum P uptake of about 40 kg ha^{-1} was obtained by applying 8.9 Mg litter + 134 kg N ha^{-1} at Newton and 4.5 Mg litter + 202 kg N ha^{-1} at Mize. Safe and effective management of major plant nutrients in broiler litter may require the use of commercial N fertilizer.

Nutrient management is essential to enhance yield, quality, and persistence of hybrid bermudagrass, an important perennial forage crop in the southeastern USA (Lang and Broome, 2003). Mississippi's poultry industry produces about 450 000 Mg ha^{-1} of broiler litter annually (Morgan and Murray, 2002). This animal manure has long been used as a source of plant nutrients and as a soil amendment (Westerman et al., 1988; Sims and Wolf, 1994), particularly on grass pastures in south central Mississippi where broiler production is concentrated (Brink et al., 2002). Because most soils in the region are sandy, acid, and have low nutrient-holding capacity, and because commercial fertilizer prices continue to rise, broiler litter remains a valuable alternative to commercial fertilizer (Ball et al., 1996; Evers, 1998). A concern regarding repeated and/or heavy applications of litter to bermudagrass is the difference in nutrients applied vs. crop nutrient requirements may result in a build up of not only soil P, but also total N (Kingery et al., 1994; Brink et al., 2002). Water quality problems can occur if P enters the surface water in runoff, and processes of NO_3 leaching loss are of concern for both economic reasons and impact on groundwater quality (Daniel et al., 1994; Pote et al., 2003). A strong positive correlation between yield and nutrient uptake by Coastal bermudagrass (Robinson, 1996; Evers, 2002; Brink et al., 2003), suggests manure management practices may involve the use of commercial N fertilizer to increase P uptake from the soil and litter and reduce P runoff (Mays et al., 1980; Pant et al., 2004). A possible mechanism for increased P uptake with N fertilization is an increase in soil solution P due to enhanced activity of rhizoshpere microorganisms (Jakobsen et al., 2005).

Hybrid bermudagrass responds favorably to increasing rates of inorganic or organic N sources (Evers, 1998; Osborne et al., 1999). Response to N fertilizer is linear up to about 560 kg N ha^{-1} and then becomes quadratic (Robinson, 1996). Forage dry matter (DM) yield is often stimulated by multiple N applications (Osborne et al., 1999). Soil type appears to have a minor influence on bermudagrass response to fertilizer N, but may influence its response to broiler litter (Adeli et al., 2006). Traditionally, application has been based on yield goals and knowledge of crop N utilization from the manure, but not all of the nutrients in the litter are plant available (Sims, 1986; Brink et al., 2002). So, in addition to the challenge of measuring the amount of N applied per acre, broiler litter N can be difficult to manage owing to the unpredictable effects of volatilization, mineralization, and soil type on the amount of N that becomes available to plants during the growing season (Bitzer and Sims, 1988; Adeli et al., 2006). Organic N, which comprises the greatest percentage of N in poultry manure, mineralizes over time to different inorganic forms depending on prevailing environmental conditions (Bitzer and Sims, 1988; Sims, 1986). The amount of inorganic N available to plants is affected by chemical composition of the litter and soil processes that control the amounts of NO_3 and NH_4 in soil solution (Gordillo and Cabrera, 1997; Adeli et al., 2006).

The typical practice of surface-applying litter to perennial forages can lead to loss of N through denitrification and NH_3 volatilization. Denitrification is often less in sandy textured than loamy textured soils, and coefficients range from 5% loss in well-drained soils to 50% loss in poorly-drained soils (Barton et al., 1999).

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Abbreviations: DM, dry matter; ICP, inductively coupled plasma spectrophotometer; STP, soil test phosphorus.

Ammonia volatilization with field application of poultry litter is estimated at 5 to 24% of the total N applied (Sharpe et al., 2004). Large values for N loss suggest a potential for decreased crop yields when poultry litter is used as the sole source of N fertilizer and applications are based on N content. Because data on leaching losses of inorganic N are sparse for poultry litter, these aspects are generally neglected in estimating application rates, and therefore result in either over- or underapplication of N relative to crop needs (Edwards and Daniel, 1992; Pant et al., 2004). For Coastal bermudagrass, the difference in average N–P–K ratio in the litter (2.1:1:1.3) (Sims and Wolf, 1994) and the observed N, P, and K uptake ratio needed to reach 90% of maximum yield (9:1:6; see Robinson, 1996), means that using litter as the sole nutrient source will increase soil test phosphorus (STP) (Sharpley, 1999).

Because a STP level exceeding crop needs is a potential source of increased P losses in runoff in pastures, regulatory agencies are moving to consider allowable litter application rates based on crop P needs and site-specific STP concentrations (USEPA, 1996; Sims et al., 2000). When plant P nutrition is the basis for litter applications, achieving adequate hay production from hybrid bermudagrass may require supplementation with commercial N fertilizer (Mays et al., 1980; Ball et al., 1996). Fertilizer studies with forage crops show maximum yield response to P additions occurs only when other nutrients are not limiting (Mays et al., 1980). Day and Parker (1985) showed P removed by Coastal bermudagrass increased as N and P fertilization rates increased. The N/P application ratio was 9:1, and the increase in P uptake was due to an increase in forage yield, because forage P remained fairly constant. In a study of annual ryegrass (*Lolium multiflorum* L.)-Coastal bermudagrass on soil with low STP (18 kg ha^{-1}), Evers (2002) applied 9 Mg litter ha^{-1} (equivalent to 330 kg N ha^{-1} and 190 kg P ha^{-1}) in fall with varying number of ammonium nitrate (57 kg N ha^{-1}) applications in spring. With annual rates of commercial $N \geq$ 112 kg ha^{-1}, the system removed about 52 kg P ha^{-1} yr^{-1}. Phosphorus uptake by Coastal bermudagrass ranged from about 14 to 19 kg ha^{-1}, and was greatest when N was applied in March, May, and July. This is much <50 kg P ha^{-1} yr^{-1} uptake by 'Alicia' bermudagrass fertilized in spring with broiler litter only (9 or 18 Mg ha^{-1}) on a soil with high STP (about 670 kg ha^{-1}) due to repeated litter applications (Brink et al., 2002). Few studies have evaluated the use of N fertilizer with litter in hybrid bermudagrass, but the available evidence suggests the amount of P removed can be influenced by the timing of mineral N applications to supplement litter N, as well as the level of soil P bioavailability.

Because forage producers often have insufficient land area for spreading broiler litter at agronomically and environmentally acceptable rates, comparative information is needed on N efficiency from commercial N fertilizer, broiler litter, and combinations of the two N sources (Sims et al., 2000). The present research was conducted to determine the appropriate combination of fertilizer N and litter needed to maximize yield of forage and major nutrients, N, P, and K, by Coastal bermudagrass on soils differing in history of broiler litter application. Results provide information for applying broiler litter safely and effectively to bermudagrass pastures.

MATERIALS AND METHODS

Studies were conducted in 1999, 2000, and 2001 at two locations in south central Mississippi, using existing swards of Coastal bermudagrass. One site near Mize, MS, was located on a commercial farm. The soil is Savannah fine sandy loam (fine-loamy, siliceaous, semiactive, thermic Typic Fraqiudult), which consists of moderately drained, strongly acid or very strongly acid soils. The second site near Newton, MS, was located at the Mississippi Agriculture and Forestry Experiment Station (MAFES) Coastal Plain Experiment Station. The soil is Ruston fine sandy loam (fine-loamy, siliceaous, semiactive, thermic Typic Paleudult), which consists of well-drained, medium acid to very strongly acid soils. Both Ruston and Savannah soils formed in loamy materials. The pasture at Mize is typical of many in the region where broiler litter has been applied to bermudagrass on an N basis (about 9.0 Mg ha^{-1} yr^{-1}) for 30+ years. The pasture at Newton has no known history of broiler litter application. In spring 1999, the bermudagrass sward was cleared of any weeds or senesced plant material, and 4- by 6-m plots were arranged in a randomized complete block design with four replicates.

The litter at Mize was obtained from a nearby broiler house at each application date. The litter at Newton was delivered from a house in spring of each year and stored outdoors under a polyethylene cover. Subsamples of broiler litter were obtained for percent moisture and nutrient determinations before each application. The moisture content averaged 25% and varied little despite a wide range of sampling dates. In general, the nutrient composition changed little for either source, so laboratory results from April applications were used to represent an approximate average of the major nutrients applied (Table 1). Broiler litter rates of 0, 4.5, 8.9, 13.4, and 17.9 Mg ha^{-1} yr^{-1} were applied by hand on a "as is basis" by monthly applications of 4.5 Mg ha^{-1} from April to July as needed to achieve the desired rate. Broiler litter treatments of 0, 4.5, 8.9, and 13.4 Mg ha^{-1} yr^{-1} were supplemented with 67 kg N ha^{-1} in months that no litter was applied (Table 2).Thus, the recommended rate of N fertilizer of about 269 kg N ha^{-1} yr^{-1}

Table 1. Broiler litter pH and concentration of selected fertilizers in broiler litter applied in April to small plots of Coastal bermudagrass at Newton, MS and Mize, MS in 1999, 2000, and 2001.

Year	Location	pH	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
			g kg^{-1}					mg kg^{-1}			
1999	Newton	7.4	35.7	17.6	25.8	26.6	5.4	621	1581	639	449
	Mize	7.5	38.3	24.2	31.3	31.0	7.7	838	832	837	591
2000	Newton	7.6	31.8	18.6	26.4	27.1	5.7	648	1985	692	496
	Mize	7.7	34.9	22.5	29.6	30.1	6.1	687	837	631	416
2001	Newton	7.5	33.1	20.1	26.7	26.8	6.0	496	2003	476	409
	Mize	7.4	32.5	20.8	29.1	30.9	6.4	541	1033	657	455

Table 2. Treatment combinations applied to small plots of Coastal bermudagrass to substitute broiler litter N with commercial fertilizer (NH_4NO_3, 34–0–0).

Broiler litter application	Litter rate†	Fertilizer N application‡	Total N rate (Litter-N + NH_4NO_3–N)‡§ Newton	Mize
4.5 Mg mo^{-1}	Mg ha^{-1} yr^{-1}	67 kg mo^{-1}	— kg ha^{-1} —	
April, May, June, July	17.9		300	315
April, May, June	13.4	July	291	303
April, May	8.9	June, July	283	291
April	4.5	May, June, July	276	285
	0	April, May, June, July	269	269

† Based on average N content in litter and fertilization rate of that N, applying 17.9 Mg litter ha^{-1} would meet annual N requirement of 269 kg ha^{-1} (see Table 1). A rate of 4.5 Mg litter ha^{-1} is expected to meet annual P requirement.
‡ Assumes 50% of N in litter is available for plant uptake during the first year.
§ Assumes 100% of N applied as 34–0–0 is available for plant uptake.

for hybrid bermudagrass production in Mississippi (Lang and Broome, 2003) was first met with broiler litter and then with fertilizer N. We assumed 50% of litter N would be plant available in each growing season, which is lower than estimates obtained from incubation studies. For instance, Gordillo and Cabrera (1997) reported 47 to 87% mineralization of the organic N in 15 samples of broiler litter, and Bitzer and Sims (1988) reported 66% mineralization of organic N in 140 d. The total amount of N applied was based on yield goal and did not account for any residual soil N. Under these conditions, a rate of 17.9 Mg litter ha^{-1} should meet the annual N requirement to maintain Coastal bermudagrass yields of 9 to 13 Mg ha^{-1} (Day and Parker, 1985; Lang and Broome, 2003). Similarly, a rate of 4.5 Mg ha^{-1} litter should meet the annual P requirement, and 13.4 Mg ha^{-1} the annual K requirement. The various fertilizer/litter treatments were applied either before a harvest in April to forage that was recently mowed to remove senesced material or immediately after each harvest in all other months, unless no harvest took place (see below), in which case the treatment was applied to standing forage.

Forage harvests began in late May to early June, and continued at approximately 30-d intervals depending on rainfall and plant growth patterns. Plots were harvested five times in 1999, three times in 2000, and four times in 2001. Forage DM yield was determined by cutting a 1- by 6-m swath at a 7-cm stubble height through the center of each plot using a sicklebar mower. Subsamples (600–800 g) of forage were dried at 65°C for 48 h and the dry weight recorded. The dry forage was ground to pass a 1-mm screen, sealed in plastic containers, and subsequently analyzed for mineral nutrients. Forage nutrient uptake was calculated as the product of DM yield and nutrient concentration at each harvest, and values were summed across all harvests within each year. Efficiency of N and P uptake for the growing season was estimated by dividing total uptake in forage by the quantity applied in the litter and/or fertilizer. Efficiency values for the season were adjusted based on nutrient uptake by unfertilized check plots.

Soils were sampled at 0- to 5-cm and 5- to 15-cm depths in March 1999 before first litter application, and at 0- to 5-cm and 5- to 10-cm depths in May 2001 before the end of experiment. Four, 1-cm diameter plugs were removed from each plot and combined in a plastic storage bag. Samples were air dried and ground to 0.5-mm size. Soil nutrient concentration and pH were determined for each depth increment as described below, and the values used to calculate an average for the 0- to 15-cm depth in 1999 and the 0- to 10-cm depth in 2000.

The following chemical analyses were performed on soil, broiler litter, and bermudagrass hay samples. Soil and litter pH was measured using 10-g sample mixed in 10 mL water. Soil, litter and plant total N, and total C were determined from duplicate subsamples using an automated dry combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). The concentration of P and K in forage was determined from duplicate subsamples using emission spectroscopy on an inductively coupled argon plasma optical emission spectrometer (ICP–OES) (Thermo Jarrell Ash Model 1000 ICAP, Franklin, MA). Approximately 0.8 g of plant tissue was ashed at 500°C for 4 h, and then 1.0 mL of 6 *M* HCL was added to the crucible. After 1 h, 50 mL of a double-acid solution of 0.025 *M* H_2SO_4 and 0.05 *M* HCL was added to the crucible, allowed to stand for 1 h, and then filtered through Whatman no.1 paper. Soil samples were extracted using Mehlich-3 soil extractant (1:10 soil/extractant) and the extracts analyzed for available P, and exchangeable K, Ca, and Mg using ICP–OES (Mehlich, 1984).

The six litter-N treatments (which includes unfertilized "check" plots) were repeated on the same plot areas each year. The fixed effects of treatment on annual DM yield and total nutrient uptake were analyzed separately for the Newton and Mize locations using the SAS PROC MIXED procedures (Littell et al., 1996). Year was represented as a repeated measure and block was designated as random effect. Litter rate served as the main plot and year as the subplot term because the same experimental units were measured over time. Because repeated measures analysis for years revealed a significant litter rate × year interaction for most variables, differences between litter-N treatments within a year were analyzed using PROC GLM procedures in SAS. A probability level of $P \leq 0.05$ was considered significant. Pairwise comparison of means was made using Fisher's protected Least Significant Difference (LSD). Analysis within harvest date and year involved plotting changes in forage nutrient concentration in relation to broiler litter rate ($n = 6$) and calculating simple linear correlation (r) across all N treatments and replicate plots ($n = 24$).

RESULTS AND DISCUSSION

Soil Fertility

As expected, initial soil samples indicated greater amounts of total N, available P, and exchangeable K, Mg, and Ca in pasture soil at Mize than at Newton (Table 3). High soil fertility at Mize is due to long history of broiler litter applications (Kingery et al., 1994; Brink et al., 2002). Initial STP value at 0- to 15-cm depth was 409 kg ha^{-1} at Mize and 52 kg ha^{-1} Newton. Initial soil pH was similar at both sites. At Mize, final pH at 0- to 10-cm soil depth decreased significantly from about 5.8 to 5.3 as litter N was replaced by fertilizer N. Similarly, Day and Parker (1985) noted the acidifying effects of ammonium nitrate in surface soils (0–20 cm) on a well-fertilized Fuquay loamy sand (loamy, siliceous, thermic arenic Plinthic Paleudult).

Two years of litter application led to substantial increases in total N and available P (Table 3, compare initial vs. final values); however, these increases also reflect the shallower depth of sampling in 2001 than 1999 (Kingery et al., 1994; Sharpley, 2003). At Newton, final values for soil N did not differ across treatments ($P > 0.30$). This suggests bermudagrass used most of the N supplied by

Table 3. Soil pH, total nitrogen (TN), and concentration of selected nutrients (by Mehlich-3 extractant, 1:10) at 0- to 15-cm depth in April 1999 before the study began, and at 0- to 10-cm depth in May 2001 following 2 yr of different N treatments at Newton and Mize, MS.

Location	pH	TN	P	K	Ca	Mg
		g kg^{-1}	mg kg^{-1}			
		(initial concentrations, 0–15 cm)				
Newton	6.0	0.79	23	47	997	80
Mize	5.9	1.18	183	143	587	70
Mg litter ha^{-1} + kg N ha^{-1}						
		(final concentrations, 0–10 cm)				
Newton						
0 + 269	6.0	1.20	31 c†	51 b	608 c	56 c
4.5 + 202	6.2	1.26	90 b	68 b	727 bc	87 b
8.9 + 134	6.2	1.31	117 b	73 b	791 abc	90 b
13.4 + 67	6.3	1.52	228 a	137 a	983 a	143 a
17.9 + 0	6.3	1.34	197 a	164 a	908 ab	146 a
LSD(0.05)	0.2	0.33	37	29	218	26
Mize						
0 + 269	5.3 d	1.69 c	336 b	102 c	700 b	70 c
4.5 + 202	5.4 cd	1.62 c	332 b	139 bc	651 b	75 c
8.9 + 134	5.6 bc	2.03 b	334 b	173 b	736 b	92 c
13.4 + 67	5.7 ab	2.08 b	406 b	196 b	884 b	132 b
17.9 + 0	5.8 a	2.50 a	521 a	266 a	1137 a	181 a
LSD(0.05)	0.2	0.32	98	68	243	37

† Means (n = 4) within a location followed by a different letter are significantly different using Fisher's protected LSD at the 0.05 level; otherwise, not significant.

the litter and N fertilizer treatments. By contrast, soil N at Mize increased significantly as litter rate increased, which may be explained by relatively high soil N initially and low N recovery by plants in 2000. At Mize, values for N recovery by plants provided 269 kg N ha^{-1} relative to unfertilized plants were 38% in 1999, 15% in 2000, and 52% in 2001. The corresponding values for N recovery at Newton were 45% in 1999, 30% in 2000, and 57% in 2001. Low N recovery in 2000 likely resulted from low soil moisture conditions due to lack of rainfall (discussed below). The somewhat higher N recovery at Newton was associated with 50% lower soil N (Table 3), and thus reflects a larger N limitation on plant growth, as compared to Mize.

Values for plant available P at 0- to 10-cm soil depth increased as litter rate increased, but there was not the fourfold increase expected from applying between 4.5 and 17.9 Mg litter ha^{-1} (Table 3). At Newton, the increase in soil P was accompanied by significant increases in exchangeable K, Ca, and Mg. Litter rates of 13.4 and 17.9 Mg ha^{-1} led to significantly more P, K, and Mg in soil, as compared to 4.5 and 8.9 Mg litter ha^{-1}. Values for Ca and Mg concentration were least in the commercial N only treatment, and were also somewhat lower than those observed initially. At Mize, final soil nutrient levels were greatest for 17.9 Mg litter ha^{-1} treatment, and in general, did not differ among the lower rates of litter. Plant available P and exchangeable Ca greatly exceeded the values observed initially.

Forage Yield

At Newton, a significant response to broiler litter was observed in 2000 and 2001 (Fig. 1). Combining fertilizer N with litter increased forage yield 10% in 1999, 25% in 2000, and 34% in 2001, as compared to fertilizer N only.

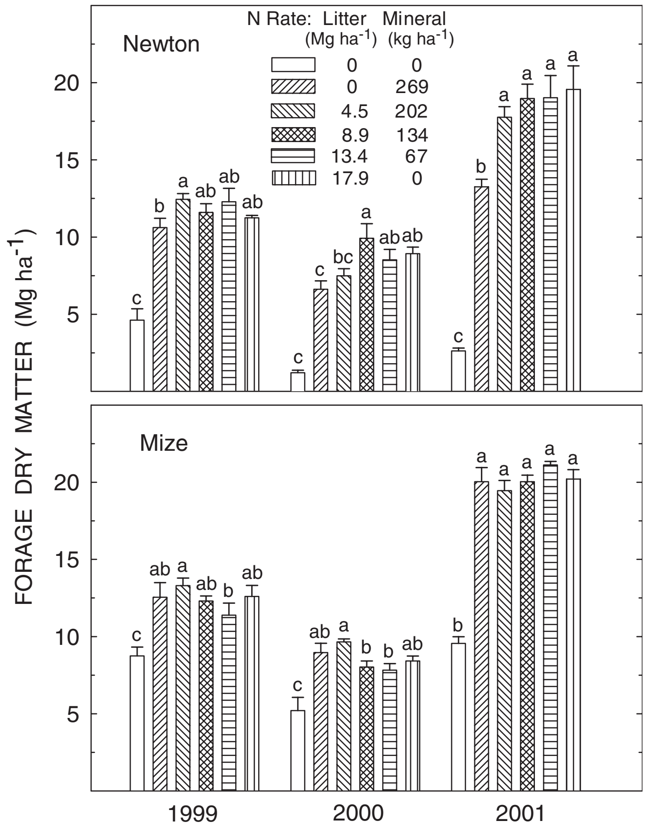

Fig. 1. Annual forage dry matter yield of Coastal bermudagrass receiving no fertilizer or combinations of fertilizer N and broiler litter to equal 269 kg ha^{-1} N in all treatments in 1999, 2000, and 2001. Values within a year with a different letter are significantly different using Fisher's protected LSD test at the 0.05 level. Values for LSD (P = 0.05) at Newton were 1.77, 1.72, and 2.59 in 1999, 2000, and 2001, respectively. Values for LSD (P = 0.05) at Mize were 1.90, 1.58, and 1.81 in 1999, 2000, and 2001, respectively.

While this result refutes our hypothesis that 269 kg N ha^{-1} would meet bermudagrass N requirement it does illustrate the value of broiler litter as a soil amendment and nutrient source for bermudagrass. We found these yield responses to litter were related to increases in soil P and K when concentrations are compared across litter rates, as well as with the initial concentration (Table 3). A significant response to litter rate at Newton suggests growth was stimulated by a larger pool of N derived from litter than would be expected based on 50% mineralization rate. Unlike Newton, forage DM at Mize did not differ significantly across the five N fertilizer treatments in 2001, or in a meaningful way in either 1999 or 2000. This result is consistent with observed increases in total soil N as litter rate increased (Table 3), which suggests more N was available than the bermudagrass used for growth. The initially high soil fertility at Mize apparently precluded significant treatment effects on forage yield.

With adequate fertilizer, Coastal bermudagrass can produce from 11.2 to 13.4 Mg hay ha^{-1} in Mississippi (Lang and Broome, 2003). When unfertilized plots were excluded, forage DM yield averaged about 12.5 Mg ha^{-1} at Newton (range: 6.6–19.5 Mg ha^{-1}) and about 13.7 Mg ha^{-1} at Mize (range: 7.8–21.1 Mg ha^{-1}). Year had a significant effect on yield at both locations, because

DM yield was greater in 2001 than either 1999 or 2000 (Fig. 1). The yield increase in 2001 likely resulted from increased soil fertility due to repeated litter applications (Table 3) and from more rainfall during the warm season, May to October (data not presented). Total rainfall during this period in 2001 was about 18% higher than the 30-yr average at each location, and amounted to 816 mm at Newton and 874 mm at Mize. Yields were somewhat greater in 1999 than 2000 (Fig. 1). This difference may be explained by two additional harvests and relatively wetter conditions in 1999. Rainfall amounts from May to October 2000 were only 400 and 277 mm at Newton and Mize, respectively. Total monthly rainfall at Newton followed closely the historical pattern except for lower amounts recorded in July all 3 yr and large amounts recorded in March and September 2001. Similarly, rainfall at Mize followed closely the long-term average, except in 2001 when large accumulations were recorded in March, June, August, and September.

Nitrogen, Potassium, and Phosphorus Uptake

Robinson (1996) summarized the response of several warm-season grasses to applied fertilizer and concluded that nutrient uptake is related closely to DM yield. But the present study differs from traditional fertilizer rate studies, because the treatments provided very similar amounts of total N (Table 1). We assumed 50% of the litter N would be available in the year of application due to mineralization and volatilization (Gordillo and Cabrera, 1997; Sharpe et al., 2004). Because this rate is lower than values reported in incubation studies (Gordillo and Cabrera, 1997; Bitzer and Sims, 1988) and because the treatments combined litter and fertilizer N in split-applications (of the same total N), we did not expect DM yield to change dramatically across treatments (Robinson, 1996). Consequently, changes in forage N, P, and K are important, not only to interpret treatment effects on nutrient uptake, but also from a nutrient management perspective, that is, to determine the need for any growth-limiting nutrient (Mays et al., 1980; Brink et al., 2004).

Robinson (1996) reported 22 g kg^{-1} is the critical N concentration in Coastal bermudagrass forage to obtain 90% of maximum yield. In the present study, forage N ranged 6.8 to 31.8 g kg^{-1} at Newton and 9.1 to 36.2 g kg^{-1} at Mize across all treatments and harvests (data not presented). Low forage N values were obtained in unfertilized 'check' treatment, and sometimes late in the season. Forage K and P concentrations fell below levels considered optimal, 15 and 2.4 g kg^{-1} for K and P, respectively, (Day and Parker, 1985; Robinson, 1996) at Newton and in unfertilized checks only. Forage K ranged from 5 to 25 g kg^{-1} at Newton, and from 14 to 34 g kg^{-1} at Mize. These data suggest K was limiting growth at Newton when <4.5 Mg litter ha^{-1} was applied, which would provide about 115 kg K ha^{-1}. At Newton, forage P increased from about 2.0 g kg^{-1} in fertilizer N only treatment to 3.2 g kg^{-1} in plants provided 17.9 Mg litter ha^{-1} yr^{-1}. Evers (2002) also observed a wide range in forage P of bermudagrass fertilized with litter and fertilizer N on soil with an STP similar to Newton (8 vs. 23 mg P kg^{-1}; Table 3). The initially high soil P at Mize (Table 3) apparently precluded any treatment effects on forage P, which changed from about 3.0 g kg^{-1} with fertilizer N only to 3.1 g kg^{-1} with 17.9 Mg ha^{-1} broiler litter.

With the exception of Mize in 2000, treatment differences in N uptake closely paralleled those observed for DM yield (Fig. 1 and 2). In general, the litter application that maximized N uptake by bermudagrass was 8.9 Mg ha^{-1} at Newton and 4.5 Mg ha^{-1} at Mize (Fig. 2). Across all treatments in 2001, N uptake averaged about 259 kg ha^{-1} at Newton and 409 kg ha^{-1} at Mize. Values for N uptake at Newton are similar to those of Evers (2002) for ryegrass–Coastal bermudagrass fertilized in the fall with 9.0 Mg ha^{-1} litter and at various times in spring with ammonium nitrate. He reported maximum N uptake of about 284 kg N ha^{-1} when fertilizer N was applied four times, and a range of 73 to 133 kg N ha^{-1} for the bermudagrass component. Our results in 2001 support evidence that N uptake by bermudagrass is enhanced under favorable growth conditions and perhaps more frequent harvests (Osborne et al., 1999; Brink et al., 2002).

At Newton, K uptake was maximized by litter rates of 8.9 Mg ha^{-1} or greater, which would provide about

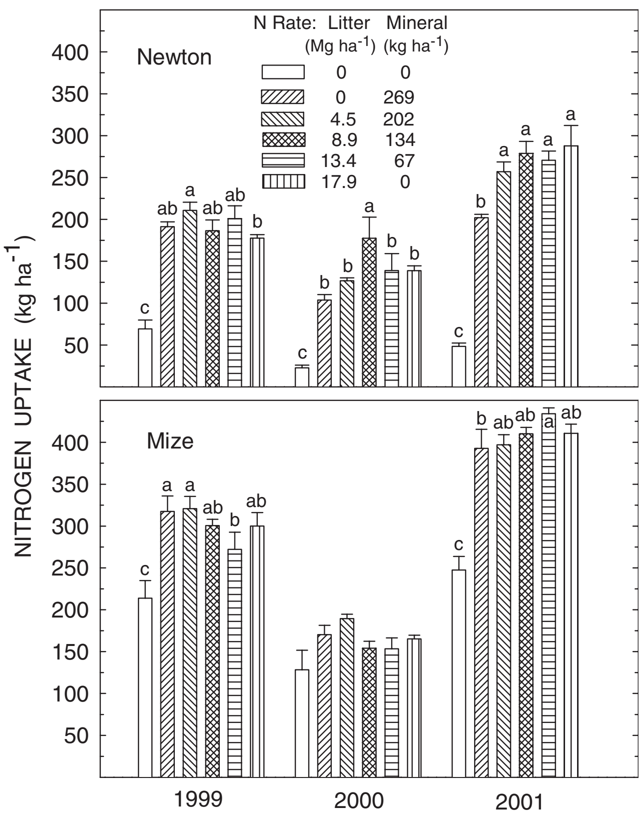

Fig. 2. Annual N uptake in Coastal bermudagrass receiving no fertilizer or combinations of fertilizer N and broiler litter to equal 269 kg ha^{-1} N in all treatments in 1999, 2000, and 2001. Values within a year with a different letter are significantly different using Fisher's protected LSD test at the 0.05 level; otherwise, not significant. Values for LSD (P = 0.05) at Newton were 32, 38, and 37 in 1999, 2000, and 2001, respectively. Values for LSD (P = 0.05) at Mize were 43, 40, and 40 in 1999, 2000, and 2001, respectively.

235 kg K ha^{-1} (Fig. 3). This fertilizer regime led to K uptake values of about 210 kg ha^{-1} in both 1999 and 2000, and 350 kg ha^{-1} in 2001. These values are higher than the 114 kg K ha^{-1} reported by Evers (2002) for Coastal bermudagrass fertilized in fall with 9 Mg ha^{-1} broiler litter. But similar to the present study, Evers (2002) reported K uptake by the annual ryegrass–Coastal bermudagrass pasture was about 332 kg ha^{-1}, which was nearly equivalent to the amount of K supplied in litter. These results support evidence that hybrid bermudagrass has high K requirement, particularly when litter K exceeds the amount required for optimal growth (Brink et al., 2003). Indeed, our results from Newton in 2001 indicated K uptake exceeded N uptake in plants provided 8.9, 13.4, and 17.9 kg ha^{-1} litter (Fig. 2 and 3) and was not strictly due to significantly more soil K (Table 3). At Mize, treatment effects on K uptake were significant in 2000 and 2001 (Fig. 3). Maximum K uptake of about 210 kg ha^{-1} was obtained using 4.5 Mg litter ha^{-1} + 202 kg N ha^{-1} in 2000. In 2001, maximum K uptake of about 350 kg ha^{-1} was obtained using 8.9 Mg ha^{-1} + 135 kg N ha^{-1}. This K uptake value is similar to that for 'Alicia' bermudagrass provided a single application of 18 Mg litter ha^{-1} in June (Brink et al., 2002).

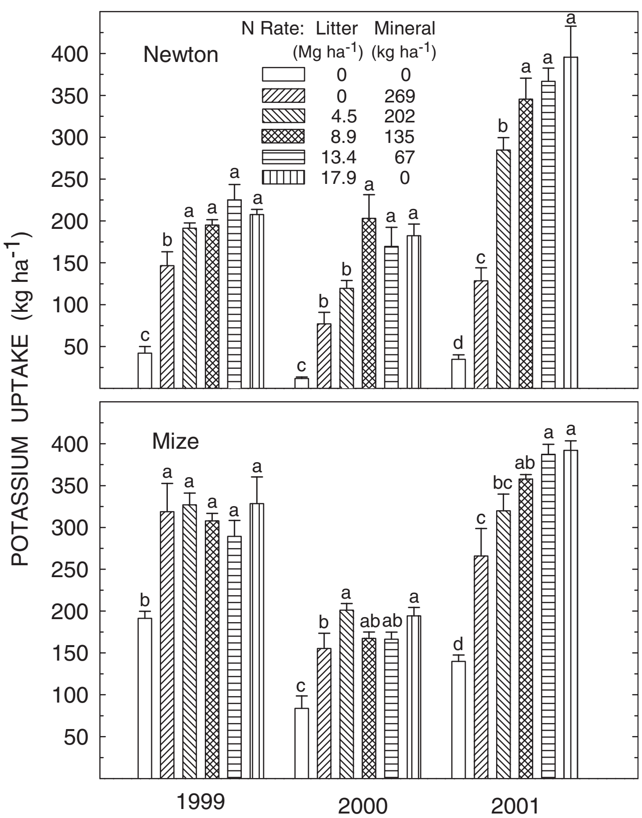

Fig. 3. Annual K uptake in Coastal bermudagrass receiving no fertilizer or combinations of fertilizer N and broiler litter to equal 269 kg ha^{-1} N in all treatments in 1999, 2000, and 2001. Values within a year with a different letter are significantly different using Fisher's protected LSD test at the 0.05 level. Values for LSD (P = 0.05) at Newton were 38, 53, and 64 in 1999, 2000, and 2001, respectively. Values for LSD (P = 0.05) at Mize were 67, 37, and 64 in 1999, 2000, and 2001, respectively.

Because P concentration is high relative to other warm-season forages, Coastal bermudagrass appears to have a high capacity for P uptake from the soil and litter (Pant et al., 2004). Nevertheless, bermudagrass P concentration is stable relative to other nutrients, so P uptake is often directly related to DM yield (Robinson, 1996; Brink et al., 2002; Evers, 2002). In the present study, P uptake was closely associated with DM yield across the different treatments, and somewhat stronger correlation (n = 24) was obtained at Mize (r = 0.92–0.98) than at Newton (r = 0.86–0.92). When data from Mize were averaged across years, the combination of 4.5 Mg litter + 202 kg N ha^{-1} (80–100 kg P ha^{-1}) produced about 14.2 Mg ha^{-1} forage and removed about 41.6 kg P ha^{-1} yr^{-1}. This same treatment at Newton led to a P uptake of only 31.9 kg ha^{-1} yr^{-1}. This level of P removal was not achieved at Newton until 8.9 Mg litter + 134 kg N ha^{-1} was applied, which would provide nearly twice the amount of P, or about 167 to 200 kg ha^{-1}. These results agree with Brink et al. (2002) that litter application rate should be <4.5 Mg ha^{-1} to limit the build up of soil P. A lower initial STP at Newton suggests P absorption capacity was greater for Ruston than Savannah soil. This may be related to the short history of litter at Newton, as Sharpley (2003) reported a relatively low P sorption capacity in Ruston surface soil (0–5 cm) that had received broiler litter for 12 yr.

Under relatively low rainfall conditions of 1999 and 2000, values for P uptake by bermudagrass were greatest numerically in treatments that combined fertilizer N with either 4.5 or 8.9 kg ha^{-1} litter (Fig. 4). The maximum amount of P removed was about 30 kg ha^{-1} at Newton in both years, and 40 kg ha^{-1} at Mize in 1999. These values exceed the maximum value of 19 kg P ha^{-1} removed by Coastal bermudagrass, when annual ryegrass–Coastal bermudagrass system was fertilized with 9.0 Mg ha^{-1} broiler litter in fall and with 56 kg N ha^{-1} in March, May, and July (Evers, 2002). Higher P uptake by bermudagrass in the present study is likely due to more mineralizable litter N in soil from split applications in spring. In 2001, fertilization with 17.9 Mg ha^{-1} litter led to P uptake of about 62 kg ha^{-1} at Newton and 58 kg ha^{-1} at Mize (Fig. 4). Brink et al. (2002) observed a somewhat lower annual P uptake, ranging from 27 to 50 kg ha^{-1}, when 18 Mg ha^{-1} litter was split applied to common and six hybrid bermudagrass cultivars on a heavily manured Savannah soil at Mize, MS. In the present study, multiple applications of litter and/or fertilizer N during the warm season may have at times enhanced DM yield, as compared to a single application (Robinson, 1996; Osborne et al., 1999). Indeed, N fertility per se apparently enhanced growth and P uptake, as applications of 269 kg N ha^{-1} increased P uptake by about 11 kg ha^{-1} at Newton and about 15 kg ha^{-1} at Mize, as compared to unfertilized plots.

CONCLUSIONS

Coastal bermudagrass fertilized with 269 kg ha^{-1} commercial N did not produce hay yields comparable to treatments that combined broiler litter and fertilizer N.

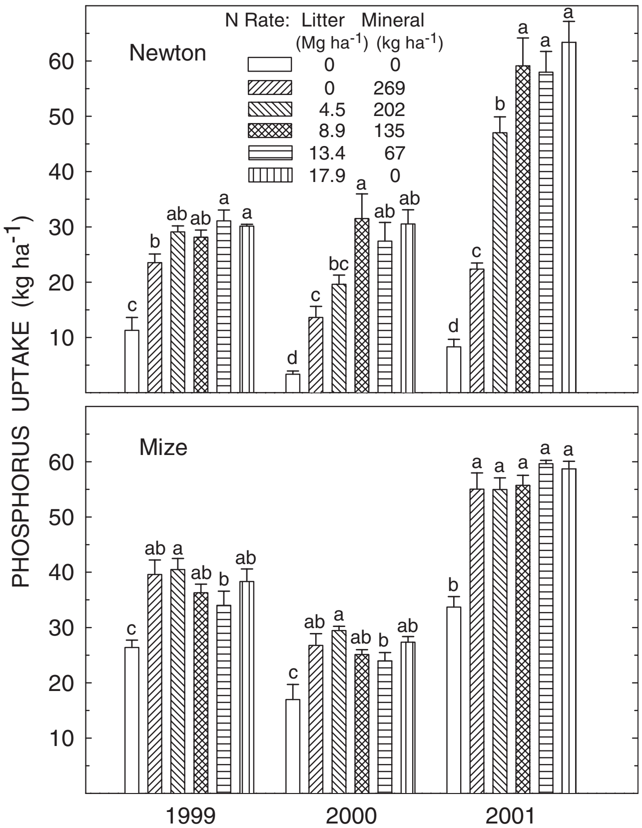

Fig. 4. Annual P uptake in Coastal bermudagrass receiving no fertilizer or combinations of fertilizer N and broiler litter to equal 269 kg ha^{-1} N in all treatments in 1999, 2000, and 2001. Values within a year with a different letter are significantly different using Fisher's protected LSD test at the 0.05 level. Values for LSD (*P* = 0.05) at Newton were 4.8, 7.3, and 8.3 in 1999, 2000, and 2001, respectively. Values for LSD (*P* = 0.05) at Mize were 5.7, 5.3, and 5.9 in 1999, 2000, and 2001, respectively.

This response is credited to the micronutrients and C provided by litter. Indeed, treatments that combined either 4.5 or 8.9 Mg litter ha^{-1} with fertilizer N produced significantly more forage, and sometimes removed more N, P, and K than plants provided fertilizer N only. Because Newton had no history of litter application, the difference in DM yield between treatments may have been a response to increased K nutrition. This is supported from increases in forage K as litter rate increased at Newton.

At Newton, the potential to combine litter and fertilizer N to maximize P uptake was evident in 2000, when the 8.9 Mg litter + 135 kg N ha^{-1} treatment removed about 20 more kg P ha^{-1} than fertilizer N only treatment. The increase in P uptake resulted from increased DM accumulation, as well as a build up of soil P. This is because 8.9 Mg ha^{-1} litter would provide about 167 to 200 kg ha^{-1} P, which is about three times the maximum uptake rate observed in this and other studies (Pant et al., 2004).

Combining 4.5 Mg ha^{-1} litter in April with applications of 67 kg ha^{-1} N in May, June, and July appeared to maximize yield of forage and nutrients in Coastal bermudagrass. This combination is appropriate when P nutrition is the basis for litter applications, because soil P would not continue to increase due to underutilization by bermudagrass (Brink et al., 2002). Because forage N requirements are often ignored when P is used as the basis of nutrient management, effective management of P in litter and soil may require the use of commercial N fertilizer. Although N fertilization of bermudagrass is costly, the practice may increase P uptake from the soil and broiler litter, and reduce P runoff in pastures.

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